CNLS Workshop
Advances in Raman-Based, High-Speed Photonics:
Raman Amplifiers, Data Transmission, and Signal Processing

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"Distributed Raman Amplification in deployed Standard Monomode Fiber Links - Measurement and Field Tests"

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Outline

- Introduction

Reviewing previous work on DRA at Deutsche Telekom

- Unrepeatered 40G RZ transmission
  over 252 km SMF using DRA

- Unrepeatered 160G RZ transmission
  over 116 km field-installed SMF using DRA

Current work related to DRA at Deutsche Telekom

- Re-scaling existing $g_R(\lambda)$ data to deployed fibers

- Field-test of commercial 40 Gbit/s/λ systems using DRA

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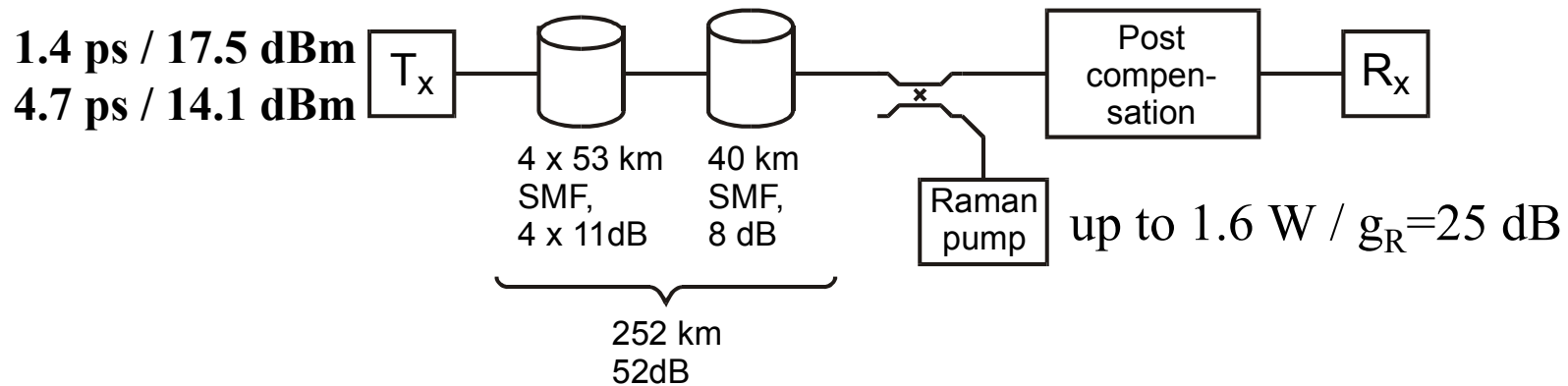Reviewing previous work on DRA at Deutsche Telekom

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- Unrepeatered 160G RZ transmission
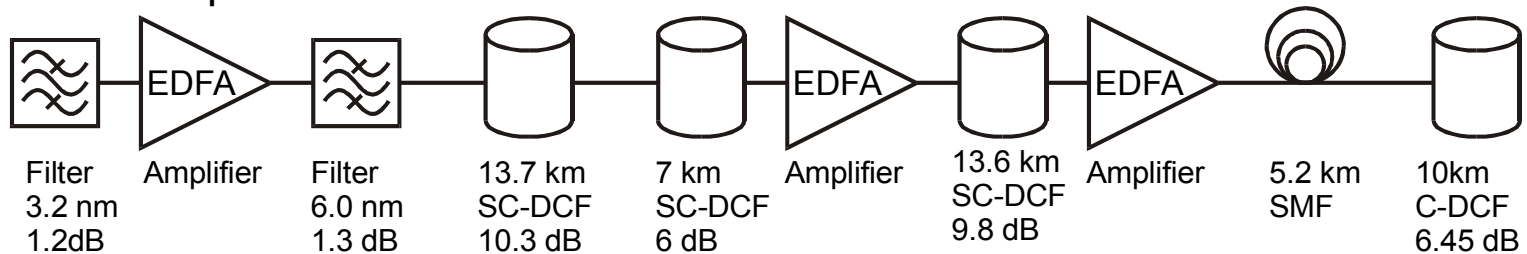 over 116 km field-installed SMF using DRA

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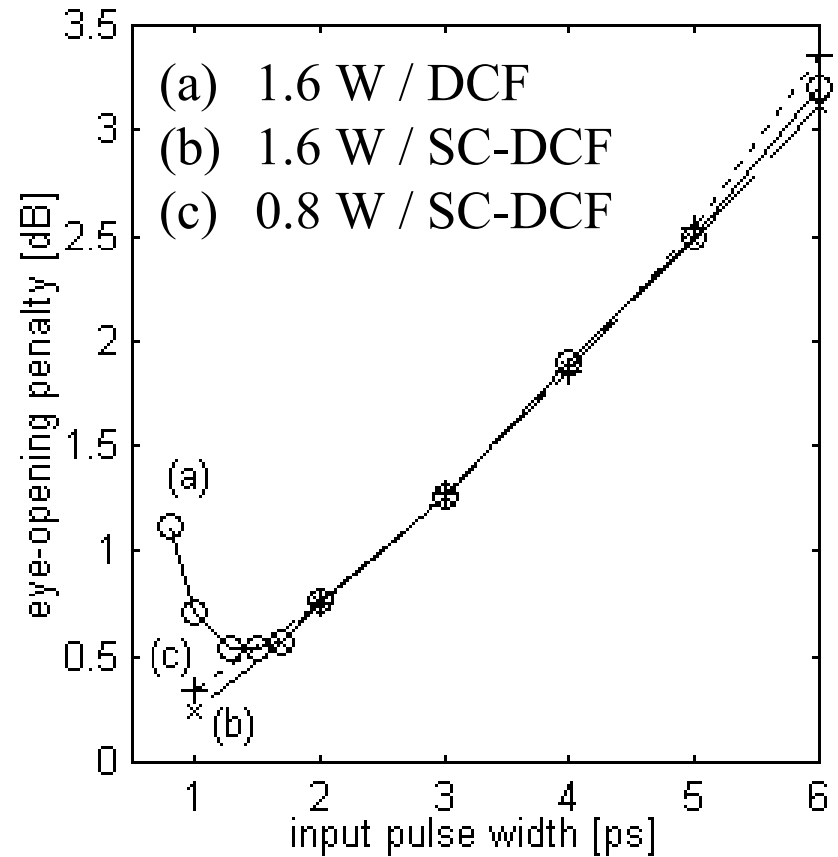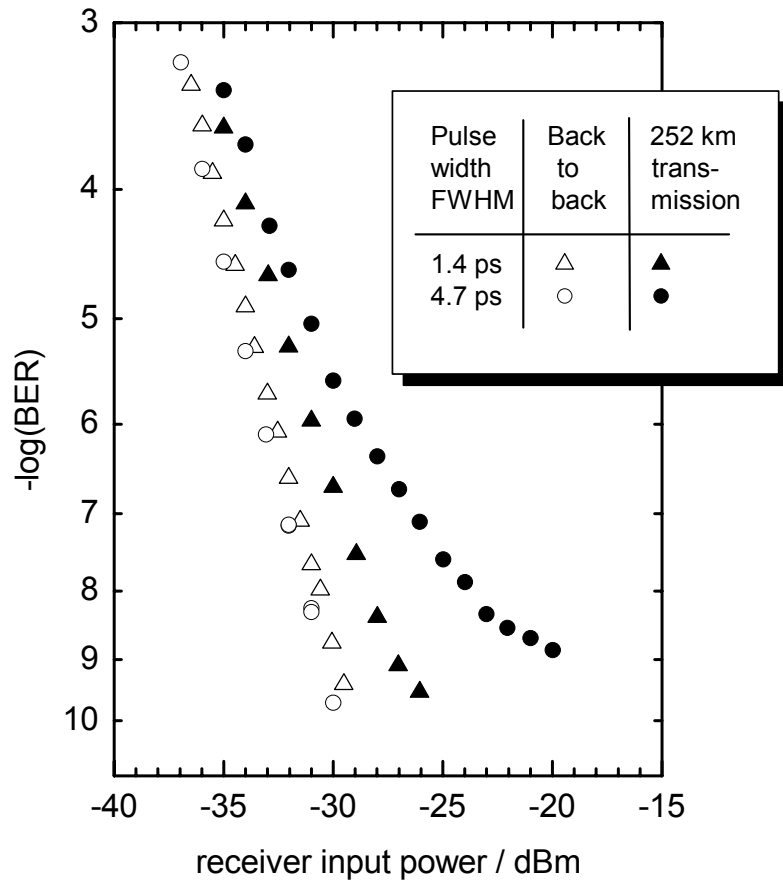- Field-test of commercial 40 Gbit/s/λ systems using DRA

Unrepeatered 40G RZ transmission
over 252 km SMF using DRA
- experimental set-up -

1.4 ps / 17.5 dBm
4.7 ps / 14.1 dBm

T_x

4 x 53 km
SMF,
4 x 11dB

40 km
SMF,
8 dB

Raman
pump

up to 1.6 W / g_R=25 dB

Post
compen-
sation

R_x

252 km
52dB

Post compensation:

EDFA

EDFA

EDFA

Filter
3.2 nm
1.2dB

Amplifier

Filter
6.0 nm
1.3 dB

13.7 km
SC-DCF
10.3 dB

7 km
SC-DCF
6 dB

Amplifier

13.6 km
SC-DCF
9.8 dB

Amplifier

5.2 km
SMF

10km
C-DCF
6.45 dB

Unrepeatered 40G RZ transmission
over 252 km SMF using DRA
- measurement results -

Pulse width FWHM	Back to back	252 km trans- mission
1.4 ps	△	▲
4.7 ps	○	●

-log(BER)

receiver input power / dBm

(a) 1.6 W / DCF
(b) 1.6 W / SC-DCF
(c) 0.8 W / SC-DCF

eye-opening penalty [dB]

input pulse width [ps]
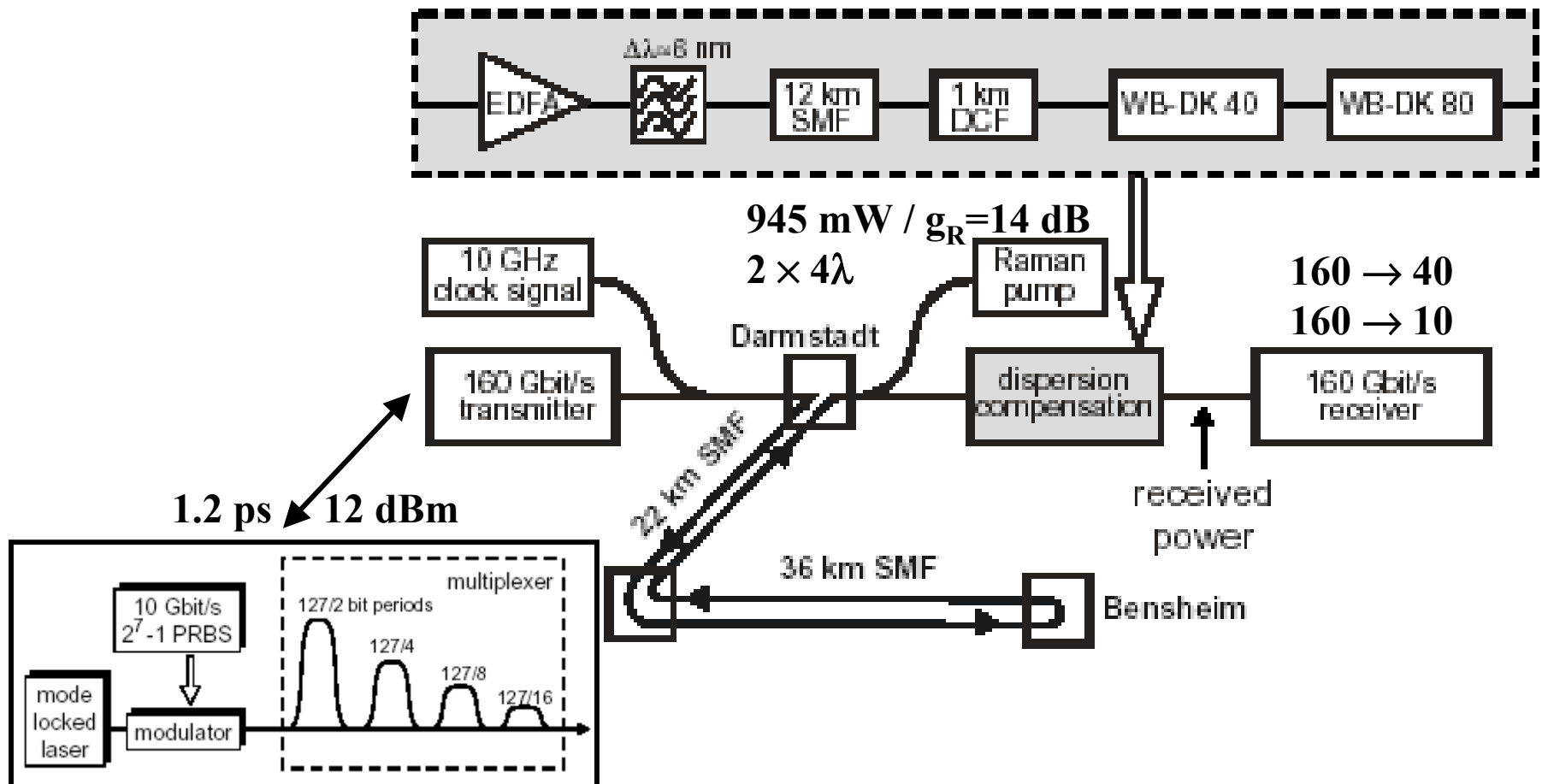
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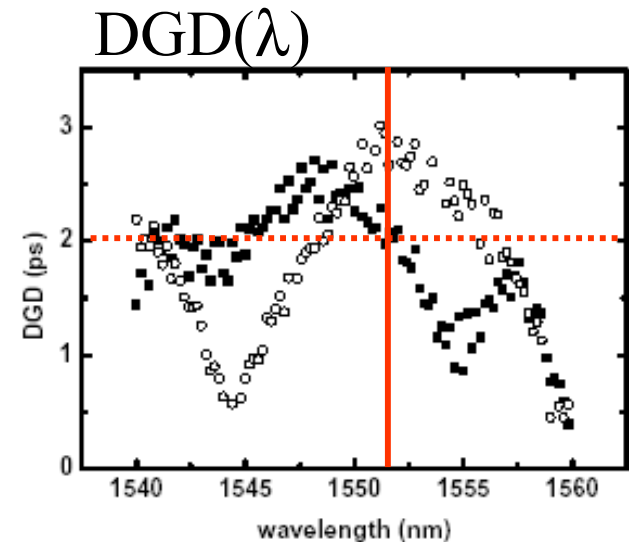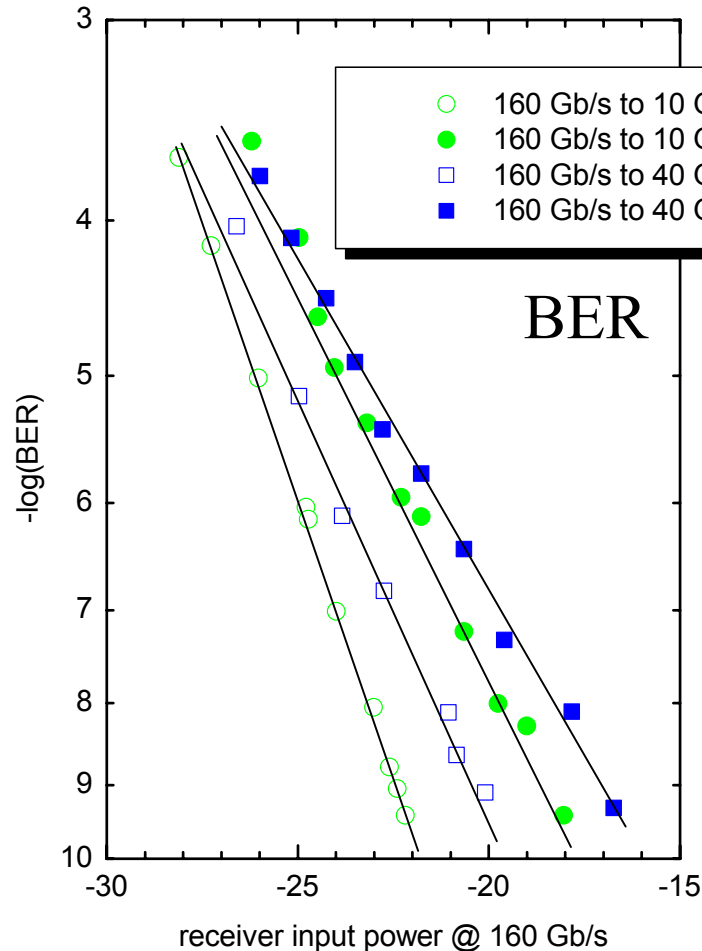 over 116 km field-installed SMF using DRA

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Unrepeatered 160G RZ transmission
over 116 km field-installed SMF using DRA
- experimental set-up -

Unrepeatered 160G RZ transmission
over 116 km field-installed SMF using DRA
- measurement results -

BER

Legend:
- ○ 160 Gb/s to 10 Gb/s back-to-back
- ● 160 Gb/s to 10 Gb/s over 116 km SMF
- □ 160 Gb/s to 40 Gb/s back-to-back
- ■ 160 Gb/s to 40 Gb/s over 116 km SMF

y-axis: -log(BER)
x-axis: receiver input power @ 160 Gb/s

DGD(λ)

y-axis: DGD (ps)
x-axis: wavelength (nm)

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Distributed Raman amplification in fiber-optic transmission systems
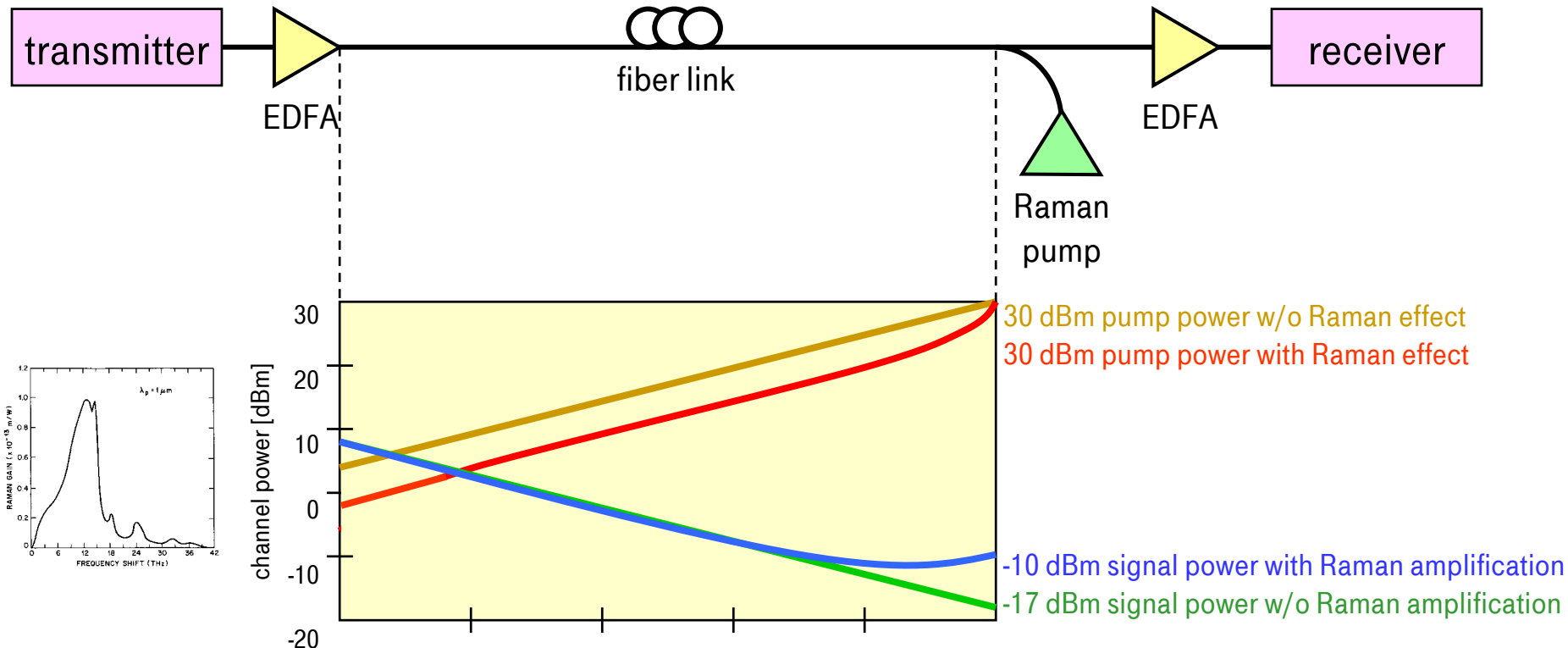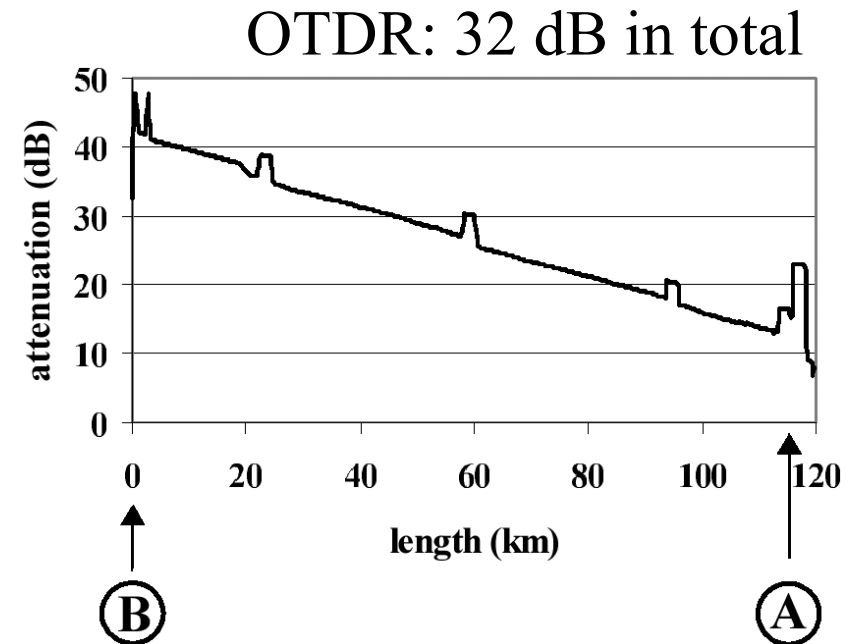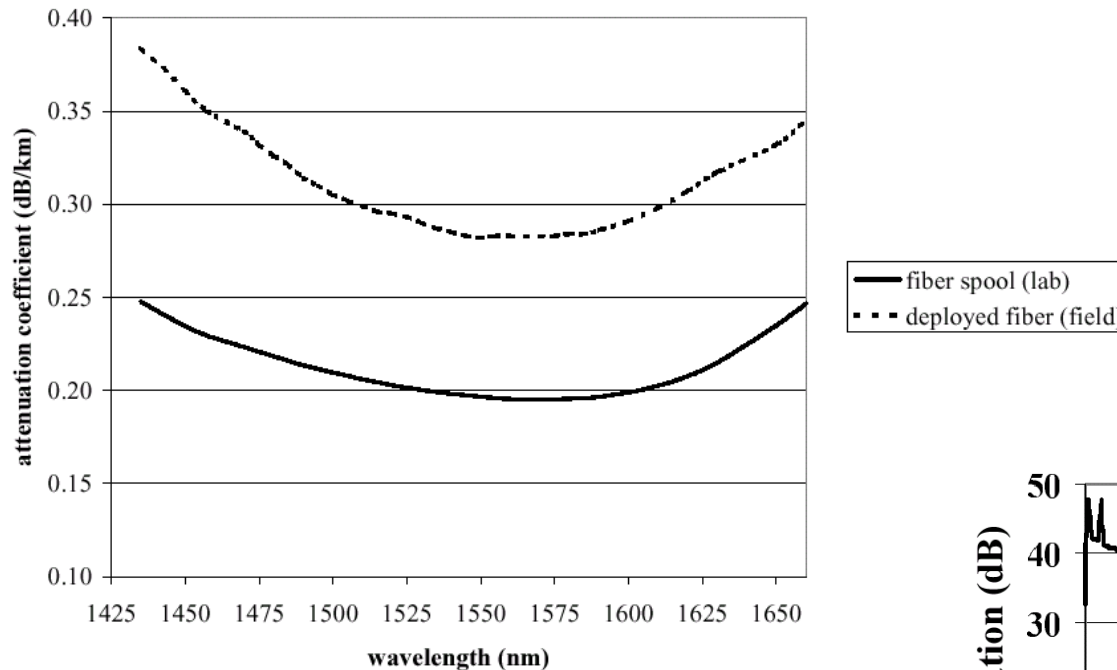

- can help to improve OSNR and to extend span and link lengths
- depens on fiber parameters (Raman gain coefficient $g_R(\lambda)$)
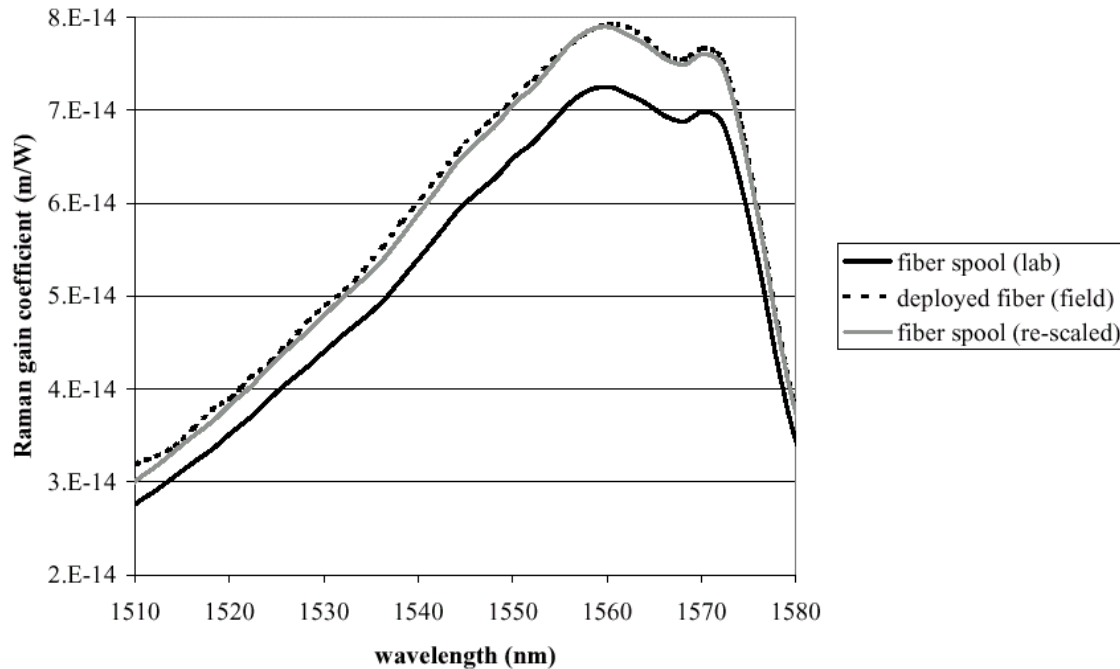- system design has to be optimized

Measurement set-up
for a deployed 115.1 km SMF link
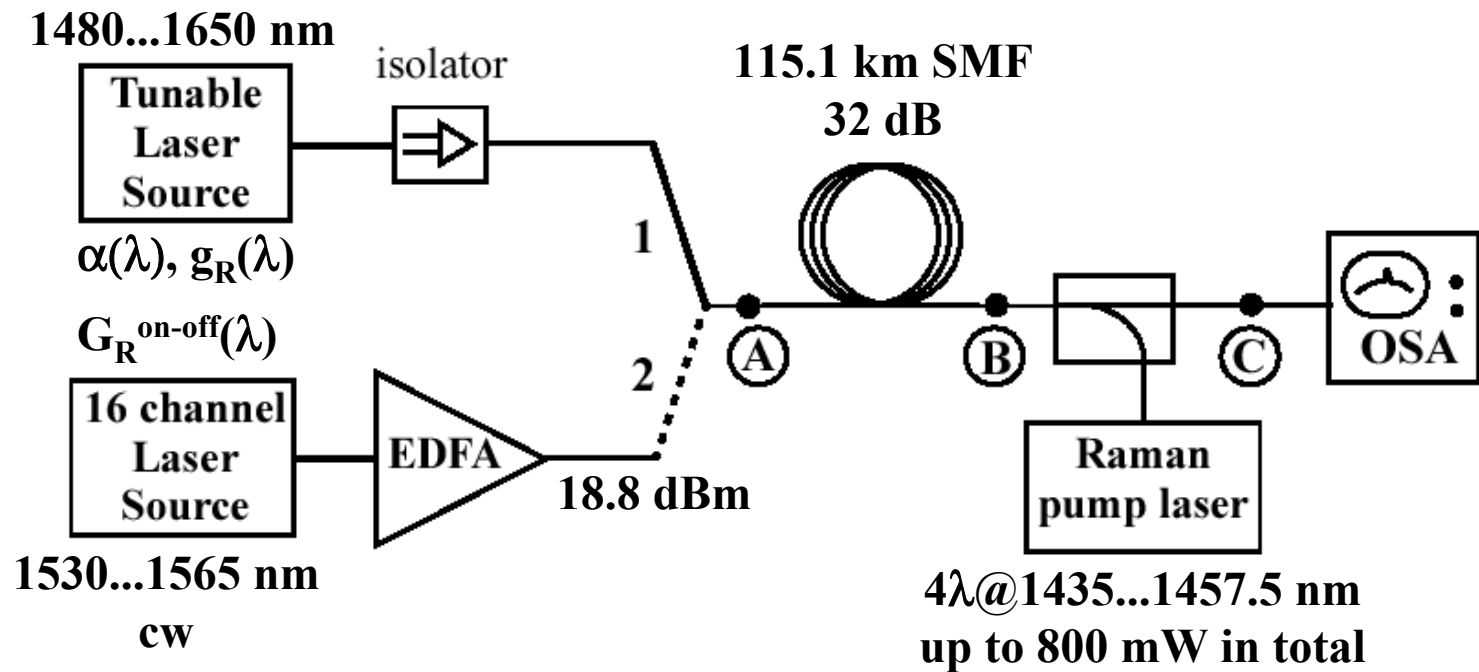
Spectral and spatial attenuation
of the deployed 115.1 km SMF link

OTDR: 32 dB in total

Measurement and re-scaling of the Raman gain coefficient

Basically, Raman gain coefficient $g_R(\lambda)$ is given by:

$$g_R(\lambda) = \frac{2 \cdot A_{eff}}{P_{pump} \cdot L_{eff}} \cdot \ln\left[G_{Raman}^{On-Off}(\lambda)\right]$$

with $\quad L_{eff} = \dfrac{1 - e^{-\alpha \cdot L}}{\alpha}$

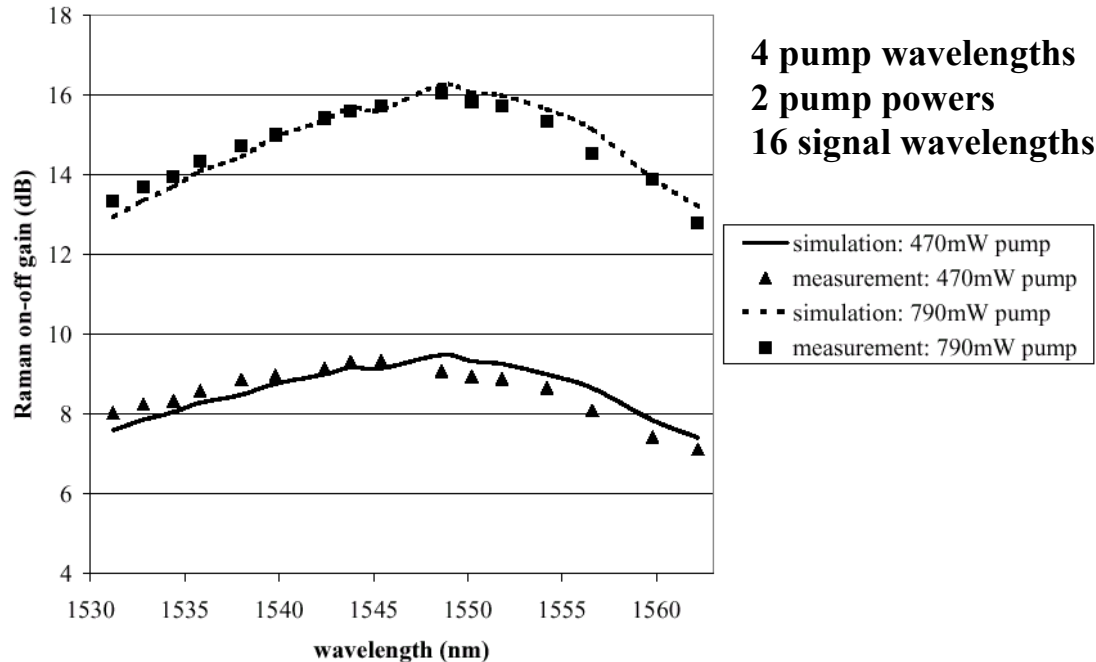|	
L_{eff}	effective fiber length at λ_{pump}
L	total length of fiber
a	attenuation at λ_{pump}
A_{eff}	effective fiber area at λ_{pump}
P_{pump}	pump power
G_{Raman}^{On-Off}	Raman On-Off Gain

(signal power ratio at fiber output for "pump on" to "pump off")

Re-scaling of the spectral Raman gain coefficient of the spooled fiber (here by a factor of 1.1) exactly matches the curve of the deployed fiber.

Comparison simulation – measurement for Raman on-off gain

4 pump wavelengths
2 pump powers
16 signal wavelengths

Input for simulation:

- $g_R(\lambda)$ of spooled/lab fiber
- $g_R(\lambda)$ of field fiber at a single wavelength
- Attenuation (in total)

Result:
Good agreement between simulations (using only a reduced set of parameters) and measurement.

Conclusion

- Cost saving is an issue
  - optimized system (link) design to reduce capex
    (requires accurate simulation based on reliable data)
  - reduced efforts for pre-installation measurements

- Accurate simulations to predict and optimize system/link design
  based on a reduced set of data:
  - Raman gain coefficient at a <u>single</u> wavelength of deployed fiber

- No need to specify
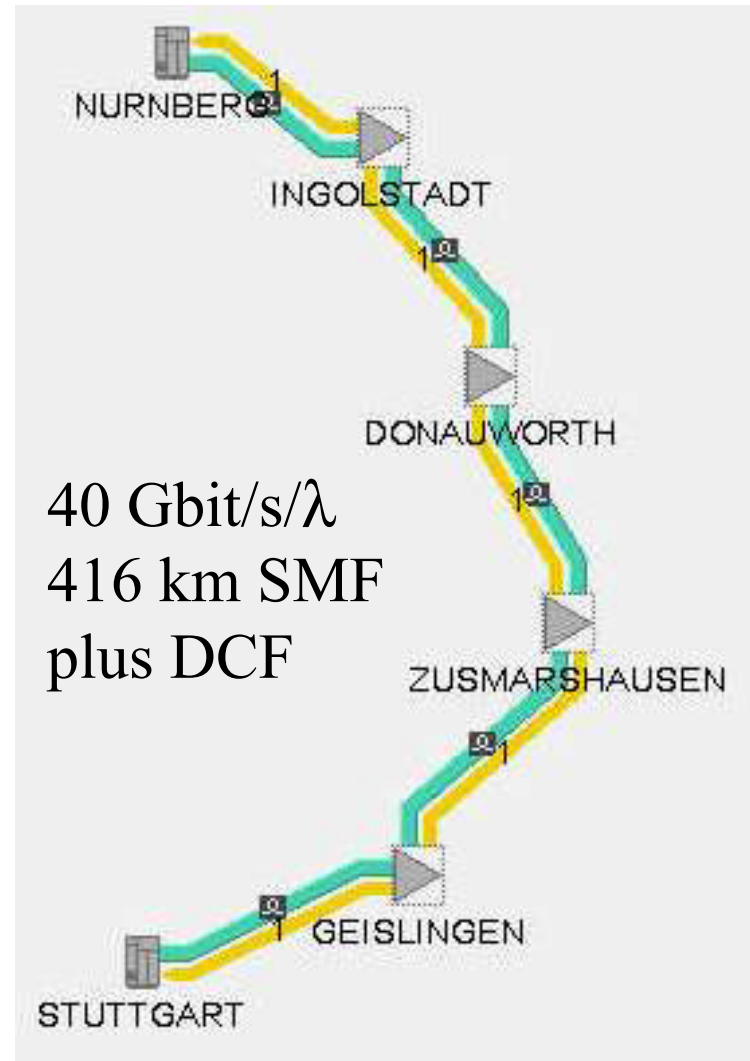 - Raman gain <u>spectrum</u>

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Commercialization of distributed Raman amplification

40 Gbit/s/λ
416 km SMF
plus DCF

NURNBERG

INGOLSTADT

DONAUWORTH

ZUSMARSHAUSEN

GEISLINGEN

STUTTGART

References

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U. Feiste, R. Ludwig, C. Schubert, J. Berger, C. Schmidt, H.G. Weber, B. Schmauss, A. Munk, B. Buchold, F. Küppers, F. Rumpf, Electronics Letters, Vol. 37, No. 7, 443-445:
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Acknowledgement